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**A CONDUCTIVITY-SENSITIVE
LIQUID LEVEL DETECTOR FOR
REACTOR ENVIRONMENT**

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SUMMARY

A conductivity-sensitive liquid level detector has been designed for the 200 to 1000^oF, 2500 psi water environment of the Loss of Fluid Test (LOFT) reactor at the National Reactor Testing Station (NRTS). The detector is a 1/8-inch diameter electrode surrounded by a cylindrical ground plane. By measurement of the electrical impedance between the electrode and the ground plane the presence of water can be detected. The success of the measurement depends upon a metal-to-ceramic seal that will withstand the environment outlined above. The metal-to-ceramic seal isolates the reactor environment from the signal cable dielectric and provides electrical isolation between the electrode and ground potential.

The probe will be mounted inside a perforated support tube in the core region of the reactor. The electrodes will be spaced 3.5 inches apart over the length of the core.

Testing the detectors in an autoclave at LOFT environmental conditions has shown the detection technique to work successfully. The signal-to-noise ratio is high allowing the instrumentation to be simple. There is a large impedance difference at the electrode between a steam and water media.

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I. INTRODUCTION

The conductivity liquid level detector was developed for the Loss of Fluid Test (LOFT) reactor core environment. The operating requirements for the detector are as follows.

Temperature Range	200-650°F with transients to 1000°F in the reactor core region
Pressure	2500 psi
Media	Water, air and/or steam
Range	2 to 6 ft depending on the location
Accuracy	± 3.5 in.
Rise time	0.500 second
Operating Life	3000-10,000 hr
Cross section	<0.5 in. diameter
Radiation	10^{20} nvt

A liquid level detector sensing the conductivity of the liquid is not a new concept. The principle has been used in many places, but it has never been used to detect liquid level over a large range in the reactor core region. The problem is to find a metal-to-ceramic seal that will withstand the high temperature, high pressure, corrosive media specified above. Many configurations and designs of seals were tried in-house and out-of-house. The most successful and reliable is a commercial seal made by Physical Sciences Corporation. This seal has been found to have low corrosion rate and a high reliability factor. Results of tests are discussed in detail below.

The probe could have been designed into many different configurations. A separate discrete level electrode configuration was chosen to provide the high reliability and accuracy. If one of the seals fails, only 5% of the information is lost when a 20-electrode probe is used. Temperature and pressure effects on the conductivity do not have to be compensated for with independent discrete level outputs.

II. DETECTOR DESIGN

The probe is designed for 2 to 21 electrodes spaced 3.5 in. apart in series (see Figure 1). Each electrode has a separate signal cable. The OD of the probe is 0.5 in. The space between the ground plane and the electrode was chosen to be less than 0.1 in. to keep the electrical impedance with water present below 10 K ohms. This makes the cable capacitance effects insignificant.

Theory of Operation

A block diagram of the detector and circuitry is shown in Figure 2. A 100 microampere, 200 Hz current source is applied at each electrode sequentially with a multiplexing circuit. The ac electrical impedance at the electrode is a function of the media between the electrode and the surrounding ground plane. The impedance with water present is a function of temperature and the impurities in the water, as shown in Figure 3. The impedance in air is much greater than with water. Liquid level is detected by the presence of a low impedance at the electrode or electrodes.

Testing

The LOFT 650°F, 2500 psi water environment was obtained in an autoclave. See Figures 4 and 5. Blowdown and flooding of the autoclave produced liquid level changes similar to those expected in LOFT experiments. Typical blowdown and flooding data for a four electrode probe are shown in Figures 6 and 7. The data were taken with an independent 10 Hz current driver for each electrode. A decrease in amplitude represents a decrease in impedance at the electrode. When water is present the impedance is between 500 and 1000 ohms. When blowing down, the boiling water interface causes an intermediate impedance output between that of water and steam for a short period. After an all-steam atmosphere is reached, it takes a few seconds for the ceramic seal to dry off before an infinite impedance is reached. This is called the tail-off of the signal. The absence of tail-off can be seen in the cold water blowdown shown in Figure 8. The ceramic is not dried out and remains approximately 100 K ohms at the electrode.

Corrosion or cracking of the ceramic seal is of concern. Corrosion tests were made on six seals at 400-hr intervals until 2000 hr in the autoclave environment was reached. An approximate corrosion rate curve is shown in Figure 9. A microphotograph of a typical seal cross section after 2000 hr in the autoclave is shown in Figure 10. The corrosion was at the most 0.040 in. out of 0.125 in. of seal. Most of the corrosion takes place in the first 400 hr. It is believed that this is caused by a concentration of silica at the surface of the ceramic caused at the time of firing the ceramic or by water isolation from the ceramic by corrosion buildup.

Fig. 1 Liquid level probe assembly.

Fig. 2 Block diagram of the liquid level detector and instrumentation with four-electrode probe output signals.

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Fig. 3 Electrode impedance to ground versus water temperature.

Fig. 4 Autoclave control panel.

Top View Autoclave

Side View Autoclave

Fig. 5 Autoclave for environmental testing.

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Fig. 6 Four electrode blowdown impedance recording.

Fig. 7 Four electrode flooding impedance recording.

Fig. 8 Four electrode cold water blowdown impedance recording.

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Fig. 9 Approximate corrosion rate of ceramic seal versus the exposure time to 2500 psi, 650°F water.

Fig. 10 Photomicrograph of a metal-to-ceramic seal after 2000 hr at 2500 psi, 650°F in water.

III. SOURCES OF ERROR

Several sources of error were considered in the probe design and were minimized.

1. A seal was selected that had a low probability of leaking. The probability of leaking in the LOFT environment is less than 0.1 after 2000 hr of operation. To improve the reliability of the probe many independent electrodes in series are used.
2. The distance between the electrode and ground plane is kept to at least 0.1 in. to allow a water fill in less than 0.1 seconds and a drain time of less than two seconds.
3. The electrode area is made large enough to make the impedance with water present below any leakage resistance in the system that might mask the signal.

IV. INSTRUMENTATION

A block diagram of the multiplexing instrumentation is shown in Figure 2. A 200 Hz, 6 volt oscillator drives current across the impedance at the electrodes of the probe. An isolation amplifier and two filters, a 60 Hz band rejection filter and a 7-pole Butterworth lowpass filter ($f_c = 2000$ Hz), and a peak detector process the voltage signal generated at each electrode. The output of the peak detector is proportional to the maximum voltage amplitude of the 200 Hz signal appearing across the probe electrodes. The voltage amplitude of the signal at the electrode is a function of the amount of liquid level on the electrode and the conductivity of the liquid. This signal information is presented in two output forms. First, a level discriminator is used to discriminate between an opened or shorted condition (each individual electrode of the probe is considered to be either completely shorted or opened). The open or short conditions of the 21 electrodes are integrated yielding an analog output. Secondly, a discrete level output is obtained. This output yields information as to the impedance at each electrode of the probe, i.e., shorted, partly shorted, or completely opened.

A reed relay scanner is used to simplify the electronics and reduce the number of data channels required for recording the data. The electrodes of the liquid level probe are sequentially scanned at a rate of 200 electrodes/second. The timing and signal identification circuitry uses five monostable multivibrators. The output of the multivibrators is synchronized with the 200 Hz oscillator.

Figure 11 shows the relationship of the various signals of the system. Signal (B) shows a typical input signal to the peak detector while scanning the first five electrodes of the liquid level probe. The pulse width of the output timing circuit is set such that the channel advance command (D) occurs just after the input signal to the peak detector has reached its peak value. The output of the peak detector is reset (F) to zero each cycle just prior to the time when its input reaches its peak value. The peak value of the input signal is automatically held by the output of the peak detector. In order to prevent the switching spikes which occur on the input signal from determining the output level, a hold command (E) is given after the desired input level has been reached. Signal (C) shows the peak detector output. The discrete output (H) consists of the peak detector output and signal identification information for use in data reduction. Just prior to scanning each electrode, a positive pulse (140 microseconds) is imposed on the peak detector signal. The data reduction technique uses the leading edge of this pulse for separating electrode information. A negative pulse prior to electrode number one is used for identifying the electrode sequence.

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Fig. 11 Relationship to multiplex circuitry signals.

V. CONCLUSIONS

Measurement of liquid level over the length of a reactor core by means of a series of discrete level water resistance measurements is a new concept. The need for an electrical isolation seal has been solved with a metal-to-ceramic seal. High reliability is obtained by using a series of independent discrete level measurements to obtain dynamic information. The output has good signal-to-noise ratio because of the large impedance change from water to steam.